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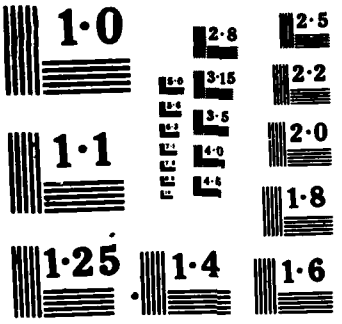

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NONSELECTIVE CHANGES IN RECEPTIVE FIELD ORGANIZATION INDUCED BY LASER IRRADIATION

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Nonselective Changes in Receptive Field Organization Induced by Laser Irradiation--Zwick, Robbins, Westgate

ABSTRACT

Receptive field organization of cells in the turtle optic tectum are complexly organized without evidence of traditional center-surround relationships. Chromatic bleaching has been conventionally used as one means of depicting the absorption spectra of underlying photopigments and their retinal interactions. Exposure of these cells to laser radiation, however, did not produce obvious spectrally selective losses. Laser light differs from incoherent light in two fundamental ways: its narrower bandwidth and its speckle pattern. Our experiments suggest that in tectal cells intense exposure to coherent light does not readily separate the underlying cone mechanisms but instead reveals some of the complexities of temporal, spatial, and chromatic interactions that can occur at higher levels of the visual pathways. Such mechanisms may be relevant to the kinds of effects observed in behavioral measures of spatial vision with non-human primates.

The laser as a research tool would appear especially suited for exploring the spatial and chromatic organization of visual cells in the nervous system. Its spectral purity and coherency should provide an ideal method for isolating the neural interconnections from receptors with different underlying photopigments. Djamagoz and Ruddock (1), for example, have reported that laser radiation of photoreceptors in the roach produces specific and predictable suppressions of excitability in horizontal cell slow potentials. Furthermore, these investigators (1) suggest that the laser provides a rapid means of differentiating rod and cone inputs into retinal cells.

However, at a more central level, where the receptive field geometry and mixture of receptor systems become more complex, the underlying receptor inputs may become obscured by the spatial, temporal, and chromatic channels later in the neural transmission network. The unique characteristics of laser light may interact with such higher order neurons in a more global and less spectrally specific manner. In this way, the advantages of laser light in analyzing the underlying neural and photochemical elements could be more limited.

Measurements of visual function in rhesus following irradiation by various laser sources have not generally revealed the strict wavelength specificity noted at the receptor level. Zwick, Bedell, and Bloom (2) showed that foveal exposure produced by a single Q-switched ruby (694 nm) laser pulse affected both the long and the short end of the spectrum. Similar work with argon (514 nm) exposures suggested loss of the intermediate cone systems as well as complex rod-cone system interactions (3,4). However, some studies using intense incoherent spectral light, do report wavelength specific effects in suppression of primate receptor sites (5).

Electrophysiological investigations in the turtle using an electro-retinogram (ERG) criterion demonstrated that suppression of the long wavelength end of the spectral sensitivity function following Krypton laser exposure was accompanied by suppression of the short to intermediate spectrum as well (6). Several additional investigations in turtle suggested that the spatial coherency of laser light might be a factor in producing such non-selective spectral changes (7,8).

In this paper, we have examined the spectral sensitivity and receptive field organization of 137 cells in the superficial layers of the optic tectum in the turtle, Pseudemys scripta elegans. The primary purpose of this study was to investigate what effects laser light has on the photopigments and the generation of retinal potentials. Our initial studies have made it obvious that the action of coherent light on the retina, and perhaps even in the neural channels themselves, was not predictably based upon a traditional

photochemical absorption model.

METHODS

A diagram of the optical and recording system is shown in Figure 1. All extracellular activity was recorded with tungsten microelectrodes in paralyzed, intubated animals. Generally, cells were held in excess of 6 hours with some being held as long as 24 to 48 hours.

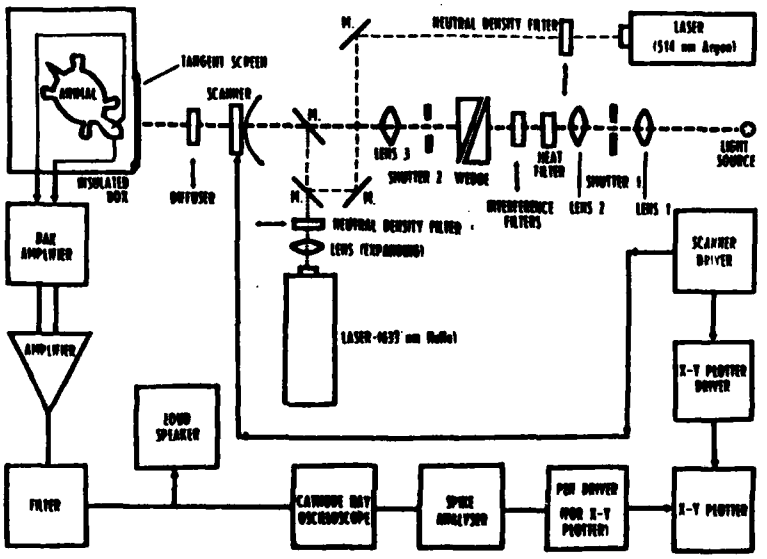

Fig 1. Optical and recording system. A standard electrometer (Bak, Model A-4) and window discriminator/Schmidt trigger (Mentor Spike Analyzer, Model N-750) were used to isolate the electrical activity of tectal cells. The amplified signal was procesed by a MED-80 microprocessor and displayed on an X-Y plotter (HP, Model 700) whose X and Y coordinates correspond to the position of a test target on the viewing screen. Tectal receptive fields were mapped on a tangent, rear-projection screen representing 20^0 by 20^0 visual field at a distance of 15-20 cm from the eye. Test spots used to map the fields were produced by a conventional incoherent, broad-band source (6V, 18a tungsten lamp) and were scanned electronically across the screen using mirror galvanometers (General Scanning Corp., Model G-330). Two triangular waveforms (Tektronix, Model FG-501) resulted in stimulus movements of different orientiations and speeds across the screen. The wavelength and intensity of the test spot could be varied by interference filters and motor-driven neutral density wedge. Laser exposure from either coherent source (514 or 633 nm) or their combination was presented either as a discrete 3^0 spot at the tangent screen or was diffused over a large portion of the screen covering the entire receptive field of the cell. Repeated exposures of either 30 or 60 minutes in duration were made allowing for measurements of the cell's spectral sensitivity and receptive field geometry between such exposures.

Coherent light from a HeNe laser (Spectra-Physics, Model 125) and an argon laser (Spectra-Physics, Model 164) was presented either as a discrete spot on a tangent screen or was diffused over a large portion of the screen covering the entire receptive field of the cell. The absolute levels of radiation over which changes in cellular activity could be elicited were from 10^{10} to 10^{14} quanta/sec/cm^2 for durations from 2 minutes to 2 hours. At the light microscopy level, no alteration of retinal tissue was observed with the maximum dosage level used.

Before and after laser irradiation, measurements of the receptive field geometry, response pattern, and spectral sensitivity of the cell were determined by both stationary and moving incoherent 3 degree targets of various intensities and wavelengths. If the cell was still responsive to light stimulation after it it was exposed again and the process repeated every 60 minutes until the cell was lost or no longer responsive. Control cells were isolated and held for similar periods of time without being exposed. In these cells no significant changes in spectral sensitivity, receptive field geometry, or in the strength or topography of the response pattern were noted during the recording period.

RESULTS

In the majority of cells isolated, both the on and off portion of the response pattern were maximally sensitive to the long wavelength region of the spectrum. The receptive field organization of these cells before exposure demonstrated no clear center-surround relationship. Most fields were dominated in or near the center by areas which produced vigorous on-off response patterns regardless of the wavelength of the test target. On-off regions were often not continuous but were separated from one another by either pure on or off regions and hence appeared more complex than the simple center-surround, spectrally opponent fields reported elsewhere.

The overall effect of laser radiation on tectal cells was to reduce the cell's sensitivity uniformly across its entire visible spectrum. Generally, the more intense the exposure, regardless of its wavelength, the stronger its effect on the responsiveness of the cell. Comparable effects could be produced by increasing the duration of lesser intense exposures or by presenting the less intense exposures multiple times separated by periods in excess of 60 minutes.

An example of the nonselective effects of laser radiation on spectral sensitivity is shown in Figure 2. In this cell the on portion of the response pattern peaked in two different spectral regions, 500 nm and 600 nm. Following 633 nm laser exposure, a rather uniform 0.5 log unit loss in sensitivity was observed across the visible spectrum. For the off portion of the response pattern, initial deficits were maximum in the long wavelength region but then

this portion of the response pattern was relatively insensitive to short and intermediate wavelengths prior to any exposure. Had the off response been as sensitive to these spectral regions as the on response was, similar uniform reductions across the visible spectrum may have also been elicited. This was certainly true in those cells where the on and off responses were more equally sensitive to different spectral regions.

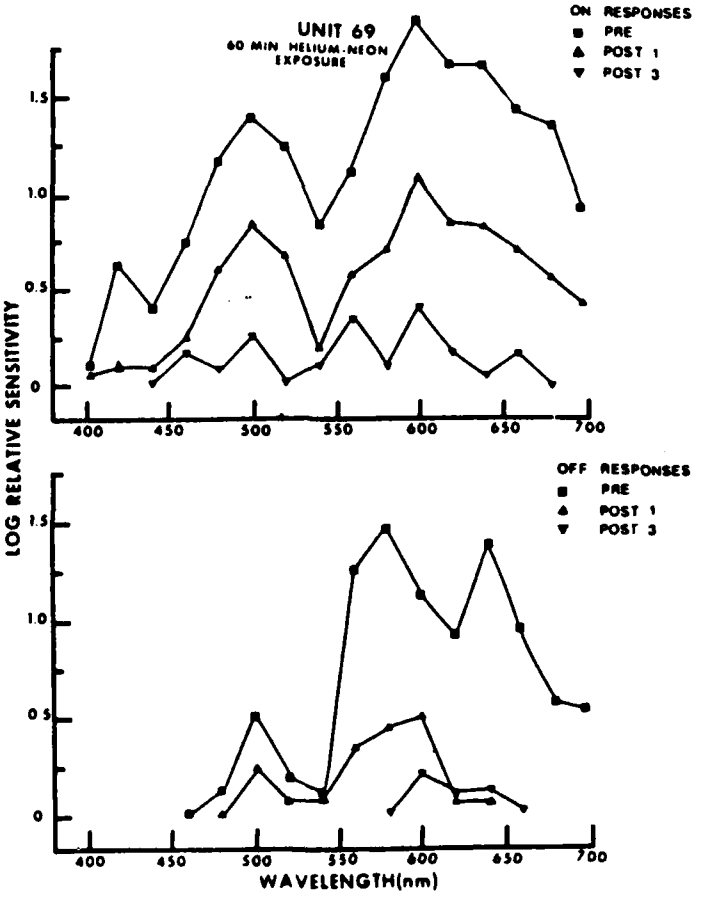

Figure 2. Exposure of a long-wavelength sensitive cell to 633 nm laser light. This cell was exposed three times to 10^{11} quanta/sec/cm^2 for 60 minutes each. The pre-exposure spectral sensitivity as well as the sensitivity following the first and third 60 minute exposure are shown in this figure. The HeNe (633 nm) exposures covered the entire receptive field and produced vigorous activity when it was first presented and later terminated. In the interim the cell was inactive. The upper graph represents the spectral sensitivity of the on portion of the response pattern, the lower graph that of the off portion. Following the third and final exposure, the cell's receptive field shrunk considerably as did the cell's overall sensitivity and eventually became totally unresponsive to any type of light stimulation.

Cells with peak sensitivities in regions of the spectrum other than the long wavelength region also were affected by long wavelength laser exposure. The exposures did little to shift the peak sensitivity of the cell before exposure. Rather, these exposures outside the maximum sensitive area produced only uniform depressions in the overall spectral sensitivity of the cell.

Exposure of cells of 514 nm laser light produced somewhat more selective effects in the intermediate spectral region but here again depressions across the entire spectrum were obvious. Initial losses in sensitivity to low level argon light were primarily produced in the intermediate and short wavelength regions of the spectrum. With repeated exposures these losses became less spectrally specific.

When combined exposures were made at 633 nm and 514 nm at relatively low power levels, the effects on the cell were much more dramatic than when either of the two wavelengths, equated in energy, were presented alone (Figure 3). However, here again the reductions were not limited or necessarily maximum in those regions of the spectrum corresponding to the peak output power of the exposure sources or the maximum absorption of the underlying photopigments. The non-selective nature of this deficit might be expected if a single type of receptor input could be postulated. Three types of cone photopigments with peak absorptions at 440, 518, and 620 nm, however, are known to exist in the turtle (9). Evidence for the neural convergence of these separate cone processes beginning at the retinal level has also been reported (10). Furthermore, the shape and breadth of our spectral sensitivity curves suggest a convergence rather than direct transmission of the separate cone mechanisms.

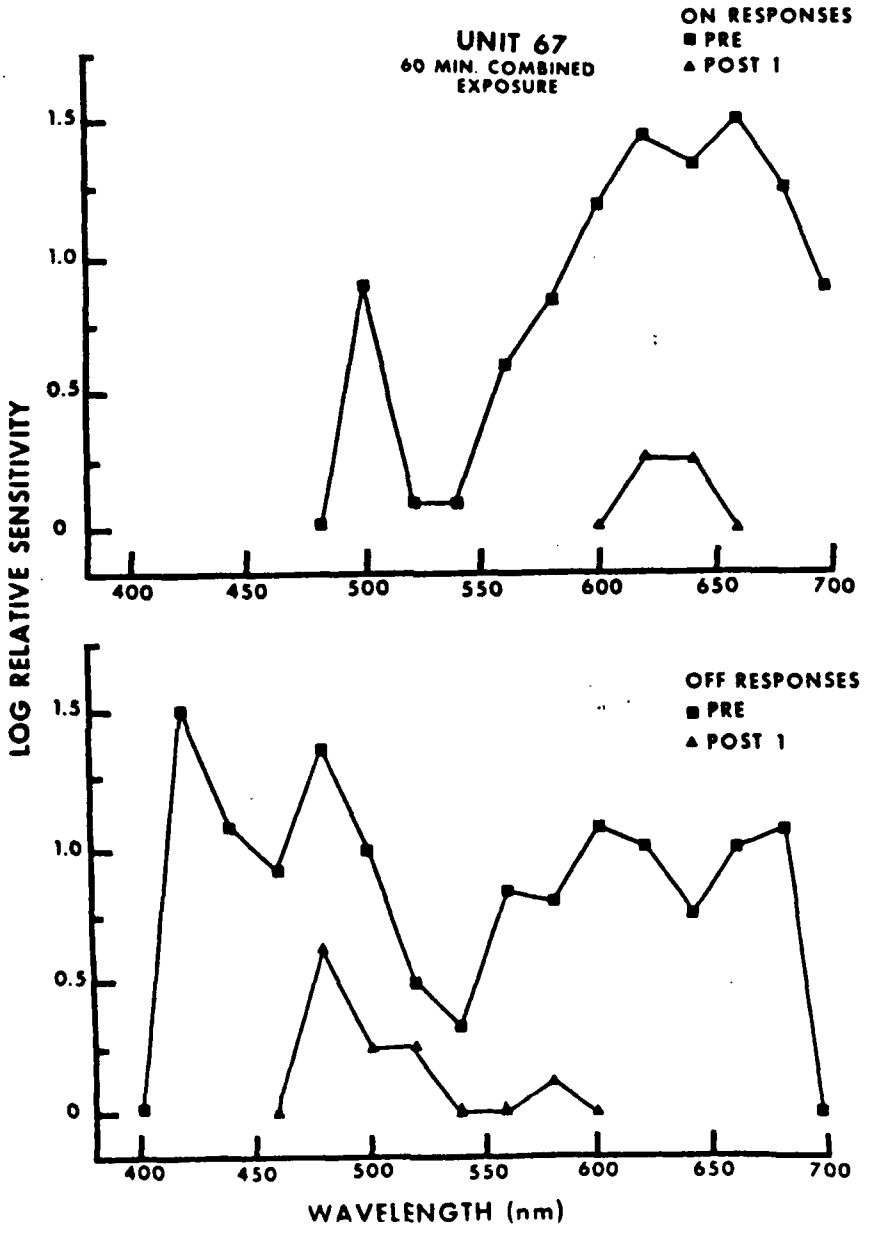

Figure 3. Comparison of the pre- and post-exposure spectral sensitivity for the on-off responses of a cell following exposure to combined 514 and 633 nm coherent light. The combined outputs from the two separate lasers were equated in terms of energy and were equal to each of the single exposures shown in the previous figure (10^{11} quanta/sec/cm^2). The exposure duration was 60 minutes and was uniformly spread across the cell's receptive field. After the first exposure, the cell's receptive field shrunk significantly as did its overall responsiveness to any type of light stimulation.

The effects of laser irradiation of the center only, periphery only, or the entire receptive field produced a similar overall constriction of the field. Most often, immediately following exposure, the overall size of the field was reduced from the periphery inward with the loss of either pure on or off regions accounting for most of the shrinkage (Figure 4). With intense enough light, the entire receptive field would constrict until the cell was no longer responsive to light stimulation. With less intense laser exposures, the initial response of the cell was an expansion of the field diameter followed subsequently by a gradual reduction of the field diameter with further exposures. This enhancement in the size of the receptive field did not correspond to any general increase in spectral sensitivity or spike activity anywhere within the receptive field. The extent and the direction of either the expansion or the eventual collapse of the field did not appear systematically related to either the type of cell isolated or the nature of the conditions surrounding the laser exposure.

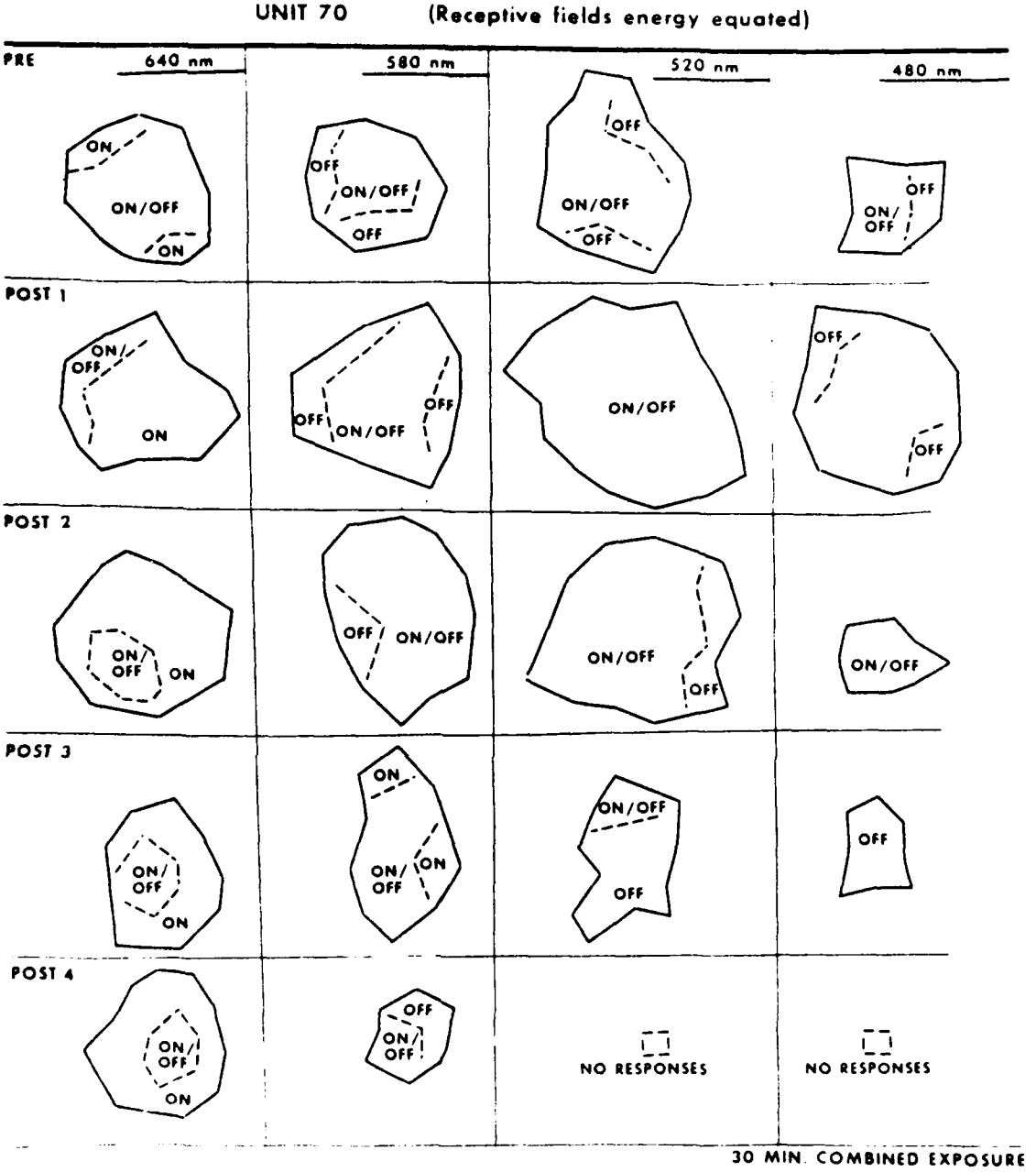

Figure 4. Plots of the receptive field of a cell following each of four combined 514 and 633 nm laser exposures. The 30 minute exposures of 10^{10} quanta/sec/cm^2 each first produced no reduction in the size of the plotted with perhaps even some expansion of the field diameter to some stimulus wavelengths. With repeated exposures, however, the dimensions of the field to all wavelengths shrunk until the cell was no longer responsive to light stimulation. Each receptive field was plotted with a different wavelength target scanned slowly across the tangent screen in various orientations. The response pattern for various positions within the field was determined by a stationary flash presented on the tangent screen (20° x 20°).

DISCUSSION

The value of the laser as an analytical tool in the separation of neural channels may be no greater than that of any other intense incoherent monochromatic source. In fact our results suggest that either the coherency or the narrow band width of laser light may artificially elicit activity not commonly observed with more traditional incoherent light sources and may overdrive the neural transmission system. Combined light from different spectral regions decreased the energy necessary for such an overload, suggesting that the addition of a second channel is more effective than a single channel alone. These results might suggest that the poential value of coherent light for visual system analysis is in the elicitation and possible unraveling of complex neural integrations resident in the higher visual pathways.

RECOMMENDATIONS

While we exposed far fewer cells to multiwavelength laser light, for those that were exposed, significantly less total exposure was required relative to cells that received single wavelength exposure of the same total energy. Thus exposure to multiwavelength sources of lower energy than single wavelength may be equally effective depending upon the biological absorption sites affected. Ocular protection from multiwavelength sources designed for maximal absorption at the eye's peak spectral sensitivity wavelength regions should be developed to counter such exposure conditions.

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